THE

MECHANIC'S GUIDE:

OR, A

Treatise

ON THE

LAWS OF MECHANICS,

as they relate to

WHEEL MACHINES:

WITH

PLAIN AND EASY RULES TO CALCULATE AND ASCERTAIN THEIR EFFECTS.

ALSO

THE GREATEST POSSIBLE ADVANTAGE TO BE OBTAINED BY SUCH MACHINES, CLEARLY POINTED OUT.

Thereby enabling a Mechanic of common Abilities to comprehend and apply them to any useful Purpose.

BY WILLIAM BIGLAND.

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PREFACE.

Having long entertained an opinion, that the laws of mechanics, relating to wheel machines, moved by the power of water, are the leaſt underſtood of any uſeful branch of learning whatever; and that nothing ſtands in ſo much need of a reform as mechanics, both as to theory and practice; nothing but a ſenſe of my want of abilities to expreſs my ideas with propriety, has prevented me from offering my mite towards their improvement.

But the neceſſity of a clear and ſimple inveſtigation of theſe laws, has at laſt induced me to undertake the taſk; and notwithſtanding the many diſadvantages I labour under, I hope I ſhall be able ſo to elucidate them as to be generally underſtood: if ſo, I have the vanity to think, that I ſhall ſet them (eſpecially as they relate to machines and engines moved by the power of water,) in a clearer light than any other author that has written on the ſubject; which will be equally to the benefit of the practical mechanic, and the honour of the ſcience.

ERRATA.

Page 4. l. 21. for *ſtream* r. *depth*—P. 5. l. 5. after *velocity* add *by the ſame power and reſiſtance*—P. 10. l. 27. after 100 *to* 1 add *here we muſt have recourſe to two wheels*—P. 11. l. 7. for *a foot* r. 2 *feet*—P. 12. l. 6. for *ſeconds* r. *feet*—P. 21. l. 22. for *bucket* r: *arm*—P. 23. l. 1. for *caſk* r. *tub*—P. 34. l. 9. for 4*th and* 5*th* r. 3*d and* 4*th*. [Note, this paſſage may be paſſed over to the table, as the ſame is better expreſſed in p. 46. from l. 19. &c.]—P. 37. l. 20. for 1:12: :6:72 r. 12:1: :36:3—P. 48. l. 25. for 3 r. 2.—P. 49. l. 10. for 1:1,5: :286:190 r. 1,5:1: :286:190—P. 58. l. 4. after *axle* add *of equal diameters*—P. 59. l. 9. after *water* add *and conſequently mechanic powers in general.*

THE

MECHANIC'S GUIDE, &c.

PART I.

BEFORE we enter on the main object of this work, it is necessary to premise, that the mechanic, if he would arrive at any eminence in his profession, must be acquainted with the common rules of arithmetic, especially with proportion, or, as it is generally denominated, the rule of three. Also, he ought to know something of decimal fractions, for it is impossible for a *mill-wright* to construct his machines judiciously, without the assistance of these necessary rules. As there is great room for improvement in the construction of mills and machines, I can assure him, that if he is not already acquainted with the use of figures to the extent I have above-mentioned, it will amply repay him immediately to make the necessary acquirement; for without this assistance he must depend solely on the direction of others, and too probably will be led in the dark, to an

erroneous concluſion, as thouſands have been before him. With this acquirement, he will not only be able to conſtruct for himſelf, but to form a deliberate and judicious opinion on the works and labours of others, whether authors or practical mechanics.

As I propoſe to inſtruct young mechanics, it will be neceſſary to explain ſome abbreviations made uſe of in this treatiſe. Two lines, thus $=$ ſignify equals; a croſs $\times$ is the ſign of multiplication. *Example;* as $2 \times 2 = 4$; which is to be read, two times two is equal to four. Alſo in ſtating the rule of proportion; *example,* as $3:6::6:12$; which is to be read, as three is to ſix, ſo is ſix to twelve; which ſignifies, that by multiplying the ſecond and third numbers together, and dividing the product by the firſt number, the quotient, or the laſt product, is the anſwer required; as may be further proved by the following *example;* as $2:4::9:18$, and as $5:3::10:6$; or, as $6:9::4:6$, &c.

If the reader knows ſome little of geometry, it will be an advantage; and the following ſeems ſufficient, as far as relates to wheel machinery:— the outſide of a circular wheel is called the *circumference;* and a ſtraight line drawn through the centre, is called the *diameter;* and half the diameter, of the circle or wheel, is called the *radius.*

By the *radiuſes* of the ſeveral wheels in any machine, I profeſs to account or deduce their ſeveral effects.

To find the diameter or circumference of any circle or wheel, when either is given, the readieſt way is to uſe 1 for the diameter, to which 3,14 is the circumference. *Example;* let the diameter be 6, then as 1 : 6 :: 3,14 : 18,84, the circumference required. But as 1 is the firſt term in the proportion, it neither multiplies nor divides; therefore by multiplying any wheel's diameter by 3,14, the product is the circumference; and by dividing any wheel's circumference by 3,14, the quotient is the diameter. *Example;* let the diameter be 7, then 7+3,14=21,98 the circumference. If the diameter be 9, then 9+3,14=28,26 the circumference. If 15,7 be the circumference, that divided by 3,14, the quotient is 5, the diameter. If 25,12 is the circumference, that divided by 3,14, the quotient is 8, the diameter requeſted: all which is ſo eaſy, that more examples are needleſs. I know not that any more of geometry is abſolutely neceſſary, in accounting for the laws of machines; their application and uſe will be amply ſhewn in the following pages.

The ratio, or proportional increaſe, of the mechanic powers may be deduced from the lever, or ſteelyard, as it is in arithmetical proportion,

as 1, 2, 3, 4, &c. But I hold that neither the lever nor ſteelyard acts truly, as a mechanic power, in any other poſition than an horizontal one: hence they are inapplicable to circular motion; therefore we muſt have recourſe to wheels, to ſupply their defect.

A wheel of one foot radius is of general uſe in finding the proportions and effects of all wheel machines; but before we can advance to calculation, we muſt find a true data to proceed from, which will bear the proof of experience. By finding the time and velocity per ſecond of any certain power, and the weight or reſiſtance upon a one-foot radius wheel, we may thereby find all the poſſible effects of the mechanic powers, by the rule of proportion, as I hope clearly to make appear.

By turning a ſtream of water on a one-foot radius wheel, ſufficient to raiſe a certain weight, I found, when the wheel had attained a regular motion, it moved with the velocity of 3,14 feet per ſecond; and by doubling the ſtream of water, it raiſed the ſame weight 6,28 feet per ſecond. Theſe data I conclude are true; as nearly ſo I believe as it is poſſible to aſcertain, excluſive of friction, which in theſe caſes was very little, as three-quarters of an ounce will move the wheel, although its weight is eleven pounds and an half. The above data, and the one-foot radius wheel, is

the foundation from which I principally deduce my calculations.

Before I proceed farther, it is proper to acquaint the reader, that all wheels move with the ſame velocity, let their diameters be what they may; and the only difference is, that large wheels being heavier than ſmall ones, cauſe more friction upon the centre; conſequently it retards their motion in proportion. This the artificer ought to have a clear idea of, as it is an eſſential part of the laws of mechanics, as may be proved by experiment.

This being premiſed, we will ſuppoſe when the power is as 2 to 1, the one-foot radius wheel moves once round in a ſecond, =6,28 feet; and as all wheels move, by the laws of nature, with the ſame number of feet per ſecond, this one-foot radius wheel affords us an eaſy rule to find the velocity of any other wheel per ſecond; alſo the number of ſeconds any wheel is in making one revolution. Thus, as one foot is to one ſecond, ſo is two feet to two ſeconds:

For the radiuſes being .	2,	4,	6,	8,	&c.	
The time of 1 revolution is	1,	2,	3,	4,	&c.	
If we proceed by diameters of	2,	3,	4,	5,	6,	&c.
The time will increaſe by half-ſeconds, as . .	1,	$1\frac{1}{2}$,	2,	$2\frac{1}{2}$,	3,	&c.

Alſo, by reducing the circumference of the one-foot radius wheel into inches, the product will be 75,36; and by dividing that by the diſtance we would have the cogs apart, the quotient will give the number of cogs the circumference will contain. I preſume 3,8 inches a proper diſtance; then 75,36 divided by 3,8, the quotient is 20 very near. So that the one-foot radius wheel will contain twenty cogs, at 3,8 inches apart. The practical mechanic may fix upon any other diſtance he pleaſes, but I adviſe him, in all caſes, to make the cogs as cloſe as poſſible, ſo that they work free of each other; as then they will work truer, wear leſs, and cauſe leſs friction in rubbing againſt each other. Alſo, as a one-foot radius is to twenty cogs, or rounds, ſo is any other wheel's radius to the number of cogs it will contain, at the ſame diſtance apart. Again, as twenty cogs, or rounds, is to the radius, ſo is the number of cogs to any other radius. Thus, ſuppoſe we want a trundle of ſixteen rounds, then, as twenty rounds is to 12 inches radius, ſo is ſixteen to the radius ſought. Thus, as 20 : 12 :: 16 : 9,6 inches, the radius that will contain ſixteen rounds in its circumference, at 3,8 inches apart; and as one foot radius is to its circumference 6,28, ſo is any other wheel's radius to its circumference. *Example;* the radius 4 given, as 1 : 6,28 : 4 :: 12,56. The radius being 6, then as 1 : 6,28 :: 6 : 18,84, the circumference.

By the foregoing rules, the following table is calculated:

Wheels' diameters.	Circumference of the wheels in feet.	Number of cogs in each wheel.	Number of feconds in one turn of each wheel.	No. of turns each wheel makes per minute; found by dividing 60 by the number of feconds each wheel is in going once round.
4	12,56	40	2,0	30,00
5	15,7	50	2,5	24,00
6	18,84	60	3,0	20,00
7	21,98	70	3,5	17,14
8	25,12	80	4,0	15,00
9	28,26	90	4,5	13,33

Trundle 2 feet diameter 20 rounds at 3,8 inches apart; velocity 6,28 feet per fecond.

The power fuppofed double the refiftance.

It muft appear evident by the foregoing rules, how eafy it is to calculate all the proportions of wheels by the help of this one-foot radius wheel, for as its radius is to all its parts, fo is any other wheel's radius to the parts thereof: and as any part of its circumference is to the radius, fo is any other wheel's circumference to the radius thereof. And I doubt not but I fhall be able to demonftrate that this one-foot radius wheel affords us as eafy rules to find the effect of machines, fimple or compound, as it does to calculate the proportions of the parts of wheels, &c.

Of Simple Circular Levers.

I HAVE already obſerved, that wheels are the only true levers; and I ſhall account for the action of all wheel machines, according as the train of the wheels conſiſts of one or more levers, &c.

A windlaſs is a ſimple mechanic power, and is well known, as it is frequently made uſe of to draw water out of wells, and for ſeveral other purpoſes. Let the turn of the handle be 12 inches, and the cylinder that the rope winds round be 3 inches radius, to determine the weight a man will raiſe thereby, by applying a power at the handle equal to 30 lb. This conſtitutes a lever as 12 the radius of a two-feet diameter circle is to 3 inches the radius of the cylinder. The rule is, to divide 12 by 3, the quotient is 4; which ſhews that the power is as 1 to 4 the weight; and by multiplying the power by 4, the product is the weight that the power will equal: thus, $30+4=120$. If the weight 120 lb. had been given, and the power 30 to raiſe it, the general rule in ſuch caſes, when the weight and power are given, is to divide the weight

by the power, and the quotient gives the proportion the wheel muſt be to the axle, as 1 is to that quotient. Thus, in the preſent caſe, the weight is 120 lb. divided by 30 the power, the quotient is 4; which ſhews the wheel muſt be in proportion to the axle or cylinder, as 4 to 1; and agreeable to the weight which is to be raiſed, the mechanic muſt adjuſt his axle accordingly, and the wheel in proportion to the axle, &c.

Example 2.—We will next propoſe a wheel and axle that a man, by applying 30 lb. to the handle of a one-foot radius, will raiſe 300 lb. Firſt divide 300 by 30, the quotient is 10, which ſhews that the radius of the wheel muſt be to the radius of the axle as 10 to 1. Note, I generally make one foot radius the ſtandard in calculating, which in this caſe is two feet diameter; then the wheel will require to be 20 feet diameter, or the axle may be 1 foot, the wheel 10; or the axle may be 6 inches diameter; then the wheel will be 5 feet diameter. In each of theſe proportions, the man will raiſe the weight in the ſame time, and nearly with as much eaſe: but it is the judgement of a mechanic to reduce the axle as ſmall as it will admit of, ſo it is ſufficient to ſupport the weight; in this caſe we will ſuppoſe 6 inches diameter ſufficient, then the wheel muſt be 5 feet diameter; and as 3 inches, or .25 parts of a foot, is to 2,5 feet, ſo is 30 to 300 lb.;

or as radius 3 : 30 :: 30 : 300; that is, as the radius 3 inches is to the radius 30 inches, so is 30 lb. to 300 lb. Observe, I distinguish the wheel, or first mover, in all cases as the first leader, and the axle the first follower; and if there are two or more levers in any machine, I call the first, where the power is applied, the first leader and follower; the second lever the second leader and follower, &c.; by which I ascertain the effect of the machine; all which will be better understood when I come to apply them to the several examples following.

I believe wheels are generally turned by spokes in the circumference, but I think it would be more convenient to have cogs round the wheel, and to be turned by a one-foot radius wheel, fixed at the side of the wheel, with cogs or rounds in it, for a man to turn it by; then 2,5 turns of this two-feet wheel will turn the five-feet wheel once round; and suppose a man turns the one-foot handle once round in a second, he will turn the great wheel once round in 2,5 seconds, and in that time raise the weight 18,84 inches.

Example 3.—Let the power be 30 lb. and the weight 3000 lb. by dividing 3000 by 30, the quotient is 100, therefore the wheel must be in proportion as 100 to 1. First, we must find the two

radiuſes, that when multiplied together their product may be 100; thus, $10 \times 10 = 100$; ſo two wheels multiplying each other will produce the ſame effect as a ſingle wheel of 200 feet diameter, and an axle of 2 feet diameter.

The wheels having cogs for a man to turn the firſt or leading wheel, by a foot diameter, with a handle one foot in the turn, as I have already obſerved, this leading wheel muſt have a one-foot radius follower upon the ſame axle, ſo fixed as to turn the ſecond leading wheel, and this ſecond leader's axle alſo one foot radius, which is to raiſe the weight by a rope going round it. The rule to find the effect of any number of multiplying wheels is, to multiply all the leaders into one ſum, and all the followers together, and divide the ſum of the leaders by the ſum of the followers; the quotient is the long end of the lever; and the proportion of the power is to the proportion of the weight as 1 is to that quotient. Thus, in the preſent example, the two leaders are 10 each, and $10 \times 10 = 100$; the followers being each one foot radius, neither multiply nor divide, therefore the proportion is as 1 : 100 :: 30 : 3000; and to find the velocity for any ſpace or time, we will ſuppoſe the man to turn the handle once round in 2 ſeconds, the velocity will be 3,14 feet per ſecond. As the man is 2 ſeconds in turning the handle once

round, the proportion is, as radius 1 is to radius 100, ſo is 2 ſeconds to 200 ſeconds, the time of one revolution; and as radius 100 is to 200 ſeconds, ſo is 3,14, the velocity per ſecond, to 6,28 feet, the ſpace the weight is raiſed in 200 ſeconds; and as 1 ſecond is to 3,14 ſeconds, ſo is 200 ſeconds to 628 feet, the number of feet the handle moves whilſt the weight is raiſed 6,28 feet. By adding a third multiplying wheel of 10 feet radius, then $10 \times 10 \times 10 = 1000$; here the long end of the lever is as 1000 to 1, and by adding a fourth wheel of the ſame radius, $10 \times 10 \times 10 \times 10 = 10{,}000$, the long end of the lever to 1 the ſhort end; ſo that by multiplying wheels, the lever may be increaſed almoſt *ad infinitum*. Hence Archimedes' problem is not only poſſible, but may be put in practice: and no doubt he had this in view when he propoſed it; for it is abſurd to ſuppoſe that ſo great a mechanic intended a long pole or bar to be infinitely extended.

Here we may obſerve, that we gain no velocity by lengthening the ends of levers; but the long end has invariably the ſame velocity of the balance; and whatever velocity the moving force and reſiſting force gives with the balance, that velocity (let it be 6,28,3,14, or any other velocity) is invariably the ſame at the increaſed end of the lever. The general rule to find the velocity of

the ſhort end, is to divide the velocity found with the balance by the difference of the ends of the lever, and the quotient is the velocity of the ſhort end: for inſtance, in the following table (p. 17), the velocity with the balance is 6,28, the lever being as 2 to 1; by dividing 6,28 by 2, the quotient is 3,14, the velocity of the ſhort end; the lever being as 3 to 1, 6,28 divided by 3, gives 2,0933, the velocity of the ſhort end, and ſo of the reſt: and to whatever length the lever is extended, viz. 10, 100, 1000, &c. this rule finds the velocity of the ſhort end, &c.

Although we may conſtruct wheels, &c. ſo that a ſmall power may equal 10,000 times its weight, yet in this caſe the balance is equal or ſuperior; as a man by a two-feet radius wheel would raiſe the 10,000 lb. in the ſame time, with as much or more eaſe, were the weight ſo circumſtanced, that it might be raiſed in ſmall detached parts, as a coil of rope, &c.; but as few ſuch caſes will occur, to which a balance can apply, we muſt have recourſe to levers as the moſt convenient method to raiſe a great weight by a ſmall power; as, for inſtance, when a man has to raiſe a weight of ten or twenty times more than his ſtrength, it may not only be neceſſary to increaſe, but to multiply the power, as is the caſe at wharfs and inns, to load and unload ſhips, waggons, &c. therefore it may

be proper to inform the reader how thofe fort of machines are conftructed.

The machines at wharfs, &c. generally have their wheels made of iron, which admit of being contracted much more than wheels made of wood; and fmall wheels will have the fame effect as large ones, if in the fame proportion; for it is the proportion, and not the largenefs of wheels that determines the effect; hence all machines ought to be contracted as much poffible, fo that no part be fo fmall as to cramp the movements of the feveral parts.—*Experiment.* Let the handle the man turns by be one foot radius, and a nut or pinion upon the fame axle with the handle, fuppofe 1,5 inches (I think one inch radius is too fmall); the pinion to turn a fecond wheel or leader, 6 inches radius, and this fecond wheel's axle to have a cylinder upon it, for the rope to wind round 3 inches radius, required the effect of this train of wheels, by a power applied at the handle equal to 30 lb. The firft leader is the handle 12 inches, the fecond leader 6 inches, $6 \times 12 = 72$; the firft follower is the pinion 1,5 inches, the fecond follower is 3 inches, $3 \times 1{,}5 = 4{,}5$, and 72 divided by 4,5, the quotient is 16; therefore, the two levers reduced into one, the long end is 16, the fhort end is 1; that is, the effect of thofe wheels is in proportion as 16 to 1, then as 1 : 16 :: 30 : 480 lb. or 4,5 : 72 ::

30 : 480 lb. the weight a man may raife by fuch a machine. Suppofe another wheel is added, 6 inches radius, and a nut or pinion 1,5 inches radius; the pinion on the fame axle with the handle turning the fecond wheel; this fecond wheel's axle having a pinion on it that turns the third wheel; this third wheel with a cylinder on it for the rope to wind round 3 inches radius; required the effect of thefe three compound levers. To reduce them to a fingle lever:—the levers are $12 \times 6 \times 6 = 432$; the followers are $1,5 \times 1,5 \times 3 = 6,75$, and 432 divided by 6,75, the quotient is 64; fo that the effect of the three levers, when reduced into one, is as 64 to 1; therefore, as 1 : 64 : : 30 : 1920 lb.; or as 6,75 : 432 : : 30 : 1920, the weight which 30 lb. at the handle will be equal to: and to determine the time a man will raife the weight any number of feet per fecond, we muft fix upon a certain velocity of the power per fecond. If a man turns a two-feet wheel once round in a fecond, the velocity will be 6,28 feet in that time; but this is too quick a motion for a man to continue for any confiderable length of time, therefore by turning the handle once round in two feconds, it will be at the rate of 3,14 feet in one fecond, which feems the moft proper velocity for a man to maintain. Then, as in the laft three levers, when reduced into one, the proportion was as 64 to 1; therefore, as radius 64 : 1 : 3,14, the velocity of the power, to ,049 parts of

a foot, or .588 parts of an inch, in one ſecond. Hence multiplying the weight ſo much more than the power is of little uſe; and I hold, that either to increaſe the power, or weight to be raiſed, ought never to be complied with, but when the neceſſity of the caſe abſolutely requires it.

If by experiment, or otherwiſe, we know the power and velocity by the balance, we may thereby find the velocity of the ſhort end of the lever, when one end is increaſed 2, 3, 4, &c. whilſt the other end remains the ſame.—*Example;* let A, in the following table, remain the ſame, and B be increaſed 2, 3, 4, &c.; in this caſe, B will have invariably the ſame velocity, and by adding 2, 3, and 4 times the weight at A, its velocity will decreaſe 2, 3, and 4 times; therefore, by lengthening the end of the lever 2, 3, and 4 times, the loſs of velocity is exactly equivalent to the weight gained. This is a general law of levers, &c. When A and B is a balance, then we ſuppoſe the velocity will be 6,28 feet per ſecond. Suppoſe a man by turning a one-foot handle apply a power of 30 lb. and the weight at A 15 lb. we will call the power at the handle B.—The weight and velocity will be ſhewn by the following table:

TABLE II.

A.	B.	W.	P.	Velocity of A.	Velocity of B.
1	1	15	30	6,28	6,28
1	2	30	30	3,14	6,28
1	3	45	30	2,093	6,28
1	4	60	30	1,57	6,28
1	50	750	30	0,1256	6,28
1	60	900	30	0,1046	6,28

The firſt column in this table, is the radius of the axle A.—The ſecond, is the increaſing radius of B.—The third the increaſing weights to balance the increaſe of the radius of B.—Fourth, the power applied at B.—Fifth, the decreaſing velocity of A.—Sixth, the invariable velocity of B.

In the foregoing table I choſe to take the example from a man turning a handle, that it may be clearly underſtood. To explain the various effects contained therein, it may be neceſſary to obſerve, we ſuppoſe the man turns the different radius wheels of B by a wheel of one-foot radius once round in a ſecond, which is equal to 6,28 feet; this velocity is the ſtandard meaſure of all the proportions. This will be more clearly explained by the following ſtatements. The ſeveral proportions are, as the radius of B is to its velocity, ſo is 1 to the velocity of A.

Thus (when the ends are a balance) as radius

1 : 6,28 :: 1 : 6,28

2 : 6,28 :: 1 : 3,14

3 : 6,28 :: 1 : 2,093
4 : 6,28 :: 1 : 1,57
50 : 6,28 :: 1 : 0,1256
60 : 6,28 :: 1 : 0,1046.

This I hold is the true law of wheels, axles, levers, &c. and will bear the proof of experiment.

It is common to ſay, that a lever is as 2 to 1, 3 to 1, &c. ; and that the long end has two and three times the velocity of the ſhort end ; which is true : but to ſuppoſe that the long end increaſes its velocity in the leaſt, by increaſing its length (which, I believe, is the general opinion of mechanics) is a moſt notorious miſtake ; it is the ſhort end only that decreaſes its velocity, the longeſt radius in all caſes repreſents the balance, which bounds the limit of velocity. If we gain velocity by lengthening the radius of wheels, &c. we gain power, for gaining velocity is in fact gaining power, which is impoſſible. It is ſaid, as a maxim in mechanics, that in gaining power we loſe time, and in gaining time we loſe power. The term *gaining power* ſhould be excluded from all treatiſes of mechanics ; it conveys a falſe idea, and it is by this idea that many miſtakes are committed. I will ſubſtitute a maxim in the place of the above which, I preſume, is better ſuited to convey the true idea, viz.—what is gained in weight or reſiſtance is loſt in velocity ; and what is gained

in velocity is loſt in weight. It may be ſeen, in the foregoing table, that this maxim only applies to the weight A, the power at B is invariably the ſame.

Several authors make a parade of finding maximums, or the greateſt advantage poſſible. In all caſes of wheels and axles, if the weight and power are given (which is generally the caſe), by dividing the weight by the power, the quotient is the proportion of the wheel, as that quotient is to one; and this rule generally determines the maximum, or greateſt advantage; which I have already explained.

PART II.

Of Water flowing through Apertures at different Depths from the Surface; and its Action on Wheel Machines, &c.

EMINENT men in all ages have tried many experiments to aſcertain the quantity and velocity of water flowing out at apertures, at different depths from the ſurface; but ſcarce two of them agree, which ſhews the difficulties attending it: and various are the opinions of water acting upon wheels; many of which, I preſume, are not only inconſiſtent, but abſurd. But vague opinions prove nothing, I will, therefore, proceed to deſcribe the experiments I have made, and the deductions I have drawn from them.

In order to prove by experiment, whether I was right in my conjectures of the water acting upon wheels, I cauſed a wheel to be made, the dimenſions of which were as follow:—the inſide of the rim 1 foot 10 inches diameter, and from out to

out ſomething above 2 feet 1,5' inches; therefore the rim was full 3 inches deep: the float boards all pointed to the centre, which is of more advantage than if they inclined to the wheel, as the water would then have ſtruck them more oblique, whereas when they point to the centre the water ſtrikes them nearer to a right angle: there are 24 floats round the wheel, which I think are too many, and that 18 or 20 would have been of more advantage, as they cut the ſtream of water too much. I had a circular channel made, to fit one quarter of the wheel, from the horizontal arm to the bottom, ſo as to encloſe one quarter of the wheel, to keep the water in the buckets cloſe. The wheel moved on points or centres, therefore the friction was ſo little as not to be regarded. The rim of the wheel was 3 inches, and a channel of the ſame width conveyed the water to the wheel, through a ſquare hole at its bottom; the water through this hole was ſo diſpoſed as to direct the ſtream, as near as poſſible, to ſtrike the middle of the floats, at the horizontal bucket. This channel that conveys the water to the wheel muſt be placed ſome height above the centre of the wheel; at the other end of the channel was a box of about 9 inches ſquare to pour the water into.

The wheel being fixed where there was a perpendicular deſcent of 10 feet, I cauſed two men

to attend with water to ſupply it therewith.—*Note*, the ſquare hole was the width of the wheel, *i. e.* 3 inches and 1,15 broad, as near as I could determine, the area of which is 3,45 inches, equal to 2 ounces of water: the axle of the wheel was 1 inch radius, and the wheel being a one-foot radius, conſequently it was as 12 to 1. I fixed a ſmall cord to the axle, and a weight of 36 ounces thereto, and the men pouring water into the aforeſaid box, the weight was raiſed 10 feet in 25 ſeconds. I repeated the experiment, and deſired the men to ſupply the wheel quicker with water; but the weight was not raiſed 10 feet one ſecond ſooner than before: and I now found, that this method of ſupplying the wheel would not determine the effect of water upon wheels, as I obſerved it moved ſometimes quicker and ſometimes ſlower. I was now at a loſs how to proceed, as there is neither a running ſtream, nor other body of water, for miles; but I bethought me of a method which anſwered my purpoſe better than I could have expected; which was, by cutting a hole at one head of a 17-gallon caſk, about 4 inches ſquare, and fitting a plug thereto; and by filling this caſk with water, putting in the plug, and turning it downwards into a tub full of water, with a channel from this tub to direct it to the wheel, which channel I ſtopped till I was ready to let the water upon the wheel; and by raiſing the water

in the caſk higher or lower, I could make the water in the channel that conveyed it to the wheel at any height I pleaſed; and I fixed upon 1, 2, and 4 inches depth, they being in duplicate ratio to each other, that I might thereby determine the proportion. I firſt cauſed the water to ſtand at 1 inch depth, took out the plug, fixed a weight of 9 ounces to be raiſed at the axle, and let the water upon the wheel: it raiſed the weight 10 feet in 19 ſeconds. I then ſet the water at 2 inches depth, and applied a weight of 18 ounces, and this the wheel raiſed in 19 ſeconds. I then cauſed the water to ſtand at 4 inches depth before I let it on the wheel, which now raiſed 36 ounces the ſame diſtance in exactly the ſame time. I repeated the experiments ſeveral times with equal ſucceſs: when theſe were made, I uſed the circular channel to keep the water cloſe to one quarter of the wheel; I then took it off, and repeated the ſame experiments with the naked wheel, and the reſult was exactly the ſame, there being not one-half of a ſecond difference in 19. This demonſtrates that the weight of water in the buckets contributes not a jot towards moving the reſiſtance; but that the wheel is wholly influenced by the momentary impulſe and weight of the water at its horizontal arm, when the velocity is 6,28 feet per ſecond: and as a dead weight can only act at the horizontal arm of a wheel, it is evident that water does the ſame.

I made a fourth experiment, by increafing the weight from 36 to 72 ounces, which I fuppofed would equal the weight and impulfe of the water at 4 inches depth: the wheel raifed this weight with the velocity of 3,14 feet per fecond. Thus the foregoing theory is proved by experiment, *i.e.* that when the impulfe and weight of water is equal to the refiftance or weight to be raifed, the velocity is 3,14 feet per fecond, and when the impulfe and weight of water is double the weight, the velocity is 6,28 feet per fecond. Hence we deduce the increafe and decreafe of the mechanic powers, according to the proportion of the power to the weight, &c. As 3,14 is the velocity of 1, or the balance, by multiplying 3,14 by 2, 3, 4, &c. the product is the velocity; thus, $3{,}14 \times 2 = 6{,}28$. $3{,}14 \times 3 = 9{,}42$. $3{,}14 \times 4 = 12{,}56$. But all velocities above 6,28 feet per fecond will fall fhort of the computed impediments of the laws of nature, &c.

That this is the true law by which water acts upon wheels, I have not the leaft doubt; and by finding the velocity of a wheel with a foot deep of water, and 144 fquare inches area, whatever velocity this body of water may give to the wheel, with a certain weight or refiftance oppofed thereto, twice the depth will give the fame velocity to twice the refiftance; and three feet deep, through the fame aperture, will give the fame velocity to three times the refiftance, &c.

From hence we deduce that the ſame law which governs the mechanic powers, governs the flowing of water through apertures at different depths from the ſurface, neither of which is governed by the laws of falling bodies in free ſpace. This might be proved by experiments with a wheel and a ſuitable ſtream of water. But when we have found the velocity of the wheel per ſecond, this will not determine the effect, or momentum of the water that is employed to move the wheel: I ſhall prove preſently, that the water acts but a very ſmall ſpace of a ſecond upon the wheel, when it moves with 4, 5, or 6 feet per ſecond.

In order to find the effect of the water in turning the wheel, I weighed and meaſured it, and found the caſk I made uſe of contained 4794 ſquare inches: and from the experiments I have made, may be drawn inferences of the greateſt importance, concerning the flowing of water through apertures, at different depths from the ſurface of a pond, reſervoir, &c. as alſo its effects upon wheels.

By experiment I found the area at 1 inch depth, through a ſquare hole 3 inches wide and 1,15 inch broad, equal to 3,45 ſquare inches; the ſtream of water was ,530122; and as 3,45 : 1 :: ,530122 : ,15339, the area of a ſtream of water that

will flow through a hole 1 inch ſquare, the depth being 1 inch from the ſurface.

This 1 inch area gives us an eaſy rule to find the area when the area of an aperture is given.

Rule:—Multiply the number of ſquare inches contained in the orifice given by the area ,15339, the product is the area flowing out at the aperture, when the depth is 1 inch; this product multiplied by any propoſed depth, gives the area of the flowing ſtream at that depth. *Example* 1ſt: Let the area be 1 inch and the depth 9 inches, then ,15339×9=1,3805 inch, the area flowing out of a 1-inch ſquare hole 9 inches below the ſurface. *Example* 2d: Let the area be 3,456, and the depth 4 inches, as in the third experiment, then ,15339×3,456=,530122, the area at 1 inch deep, and ,53×4=2,12 the area of the ſtream of water conſtantly flowing out at the aperture, 4 inches from the ſurface. *Example* 3d: Given the aperture 6 ſquare inches, the depth 12 inches, ,15339 ×6=,92034, and ,92034×12=11,04408, the area conſtantly flowing through a 6-inch hole, 12 inches below the ſurface. *Example* 4th: The area 1 foot ſquare, or 144 ſquare inches, ,15339× 144=22,088, which being multiplied by any number of inches, ſuppoſe 12, 22,088×12=265,056, the area of the flowing water. *Example* 5th: Let

the area be the ſame as the laſt, and the depth 6 feet, in the laſt example the area is found to be 265,056, and 265 × 6 the product is 1590,336 ſquare inches; the area of the flowing water through an aperture 144 ſquare inches, and 6 feet below the ſurface.

By the ſame rule may be found the quantity, or area, of a column of water flowing out at any given depth and opening from the ſurface.

By dividing the number of ſquare inches iſſuing out of any aperture by 1,728, the quotient is the number of ounces, which divided by 16 gives the number of pounds. Thus, in the 5th example, the area is 144 ſquare inches, and 6 feet deep, the area or column of water conſtantly flowing out at the aperture is 1590,336 ſquare inches; and I find by experiment the impluſe and weight of water upon a wheel is nearly equal to 4,89 times the column of water; and 1590,336 × 4,89, the product is 7776,743, which divided by 1,728, the weight of 1 ounce of water, the quotient is 4494,6, this ſum divided by 16, the quotient is 280,9 pounds, the weight and impulſe of the flowing water upon wheels. By the ſame proceſs may be found the impulſe and weight of water acting upon wheels of any other depth and apertures, &c.

I have many years been clearly of opinion, that the action of water upon wheels, was but of ſhort duration, and might be properly ſaid to act by momentary impulſes; but I ever deſpaired to find it out by rule, till I made a few experiments; by which I find the time of its action upon a wheel is limitted to ſomething leſs than 5-60 of a ſecond. I alſo find in the area of water flowing through apertures, that the colum of water only fills a proportionaal part of the area, till it is 6,52 inches deep, when the column of water and area of the aperture become equal, and at about 13 inches deep the column becomes double, and at $19\frac{1}{2}$ inches deep the column is three times the area of the aperture, &c. What will the learned critics ſay to this new doctrine, ſo widely different from any eſtabliſhed theory? So different, that I can ſcarcely truſt my own concluſions, as it ſeems almoſt impoſſible that ſo many eminent men, by almoſt innumerable experiments, ſhould none of them hit upon the true law of flowing water at different depths from the ſurface, &c. It ſeems to me, they were all miſled by conceiving that the ſame law which governs falling bodies, alſo governs the flowing of water at different depths from the ſurface of ponds, &c.; and rather than endeavour to find out any other law to account for it, tacitly believed it was the ſame, and therefore endeavoured to find out plauſible reaſons to account for the great dif-

ference between theory and experiments; not confidering it is fcarce poffible there fhould be fo great a difproportion as 5 to 8, between experiments and true theory.

I find by the experiments I have made, that the progreffive increafe of water flowing out at apertures, at different depths, is not according to the fquare root of the depths, but at 1 inch a certain quantity, at 2 inches twice that quantity, at 3 inches three times that quantity, and fo increafing in arithmetical progreffion to any depth propofed, as I have fhewn in the foregoing examples.

This law feems more confiftent with found reafon, than to fuppofe that water is governed by the fame laws as falling bodies in the air; we will allow that it flows towards the openings, or apertures, in a perpendicular direction, but it has to make its way through a much groffer fluid than air, confequently muft meet with a proportionable obftruction

It is alfo agreeable to found reafoning that it increafes according to the foregoing ratio. What is the caufe of its increafing quantity, according to the increafe of depth, but the additional preffure of the water above? And is not this increafe of preffure uniform, viz. 1 foot, 2 feet, 3 feet, &c.?

And is it not confonant to reafon, that an equal uniform increafe of preffure fhould caufe an uniform increafe of quantity flowing, &c.? This, in my opinion, has much more probability in its favour, than that the laws of accelerated motion fhould influence the flowing of water at different depths.

The experiments I have made, plainly indicate that the velocity is the fame at all depths, viz. 6,28 feet per fecond. To prove from thefe experiments that the velocity of water is the fame, through equal apertures, let the depth be what it may; and that it is not the length of the column of flowing water, but the area of the column which increafes according to the depth.

Example 1ft. The area of the aperture, in all the experiments, was 3,45 fquare inches; in this cafe the depth of water 1 inch, the quantity was 4794 fquare inches, the time of its running out 120 feconds. The area found by the foregoing rule is ,530122 fquare inches, 75,36 inches (the number contained in 6,28 feet) multiplied by ,530122 the product is 39,94992392, from which we may conclude, that the 4 in the hundred parts may be eftimated as 5, the fum will be 39,95; and 39,95 × 120, the number of feconds the water was in running out, the product is 4794, the exact

quantity of water run out: hence it is an incontestable proof, that the water flowed out of the aperture 6,28 feet per second.

In the 2d experiment the water was 2 inches deep, the time of running out 60 seconds, the area of the running stream, found by the foregoing rule, is 1,060244; 1,060244 × 75,36, the product is 79,89998784, the square inches per second; this sum multiplied by 60, the number of seconds it was in running out, the product is 4793,9992704. *Note*, it is of no use to run such great lengths into decimals, because our senses cannot distinguish such minute parts; hence I shall only take the hundred parts in future calculations, except the third decimal is above 5, which I think is sufficiently exact, except in exceeding nice calculations, which I think this subject does not require.

Experiment 3d. The depth of water 4 inches, the area is found to be 2,12 of flowing water, the time of 4794 inches running out 30 seconds: 75,36 × 2,12 the product is 159,7632, the square column of flowing water 159,7632 × 30 the product is 4792,896. Here the quantity falls short above a square inch: this does not invalidate the truth of the rule, as it is owing to the imperfectness of decimals.

I made a fourth experiment, which affords something very ſingular from the foregoing: the water was at the ſame depth as in the third experiment, viz. 4 inches, and the reſiſtance in that caſe was 36 ounces; but in this it was 72 ounces, ſuppoſed to be equal to the impulſe and weight of water flowing when the water is at 4 inches. This impulſe and weight of flowing water being only equal on a balance to the reſiſting weight, it therefore collects in the channel that conveys the water to the wheel, till it overcomes the reſiſtance, and riſes nearly to double the height to what it was in the channel in the third experiment; when the motion of the wheel becomes regular, its velocity is 3,14 feet per ſecond; but the velocity of the flowing water was 6,28 feet per ſecond, as is proved by the following calculation:—firſt, it is to be noted, that the water riſes twice the height in the channel to what it was when the reſiſtance is but half; hence it is equal in preſſure, as if the water were 8 inches deep, the area of the flowing water is 4,24: 4,24×75,36, the product is 319,5264, which multiplied by 15 ſeconds, the time the 4794 ſquare inches was in running out, the product is 4792,896.

This fourth experiment enables us to diſcover the great effect of the impulſe of water upon a

wheel, when applied to the greateſt advantage. In the 3d experiment the water being ſet at 4 inches depth, gave the wheel the velocity of 6,28 feet per ſecond, with a reſiſtance of 36 ounces at the axle: but by doubling the reſiſtance to 72 ounces, the water riſes to double the depth in the channel to what it was when the reſiſtance was 36 ounces, and the column of water flowing upon the wheel is 4,24, which before was 2,12 ſquare inches; yet this double quantity of water only gives the wheel the velocity of 3,14 feet per ſecond.—Example 5th: by increaſing the depth of water to 8 inches, the column of water gives the wheel the velocity of 6,28 feet per ſecond, with a reſiſtance of 72 ounces at the axle; yet the column of water flowing upon the wheel is only 4,24 ſquare inches. Hence we find a notable difference of water acting upon wheels under different circumſtances. In the 4th experiment, the water riſing in the channel to double the depth it was before, ſupplies the wheel with twice the quantity of water in the ſame time, viz. 12 ounces; and as 12 : 1 :: 72 : 6 ounces. This 12 ounces power, with a reſiſtance of 6 ounces, gives the wheel but 3,14 feet per ſecond; yet by doubling the depth of water to 8 inches, the ſame quantity of water only flows upon the wheel in the ſame time, yet it gives the wheel double the velocity. As the quantity of water in each caſe is exactly the ſame, it is manifeſt that

the double velocity of the wheel is wholly owing to the increaſed impulſe of the water, and not a jot to its weight. Hence the impulſe of water upon wheels, when properly applied, is far greater than any author ſeems to have thought of, and therefore makes it appear, that all the opinions they have ſet forth of water acting upon wheels, are not founded in truth.

From the 4th and 5th experiments, we are enabled to make a tolerable eſtimate of the great impulſe of water upon wheels. In the 3d experiment, the column of water was 2,12 ſquare inches; the weight of 1 inch in length is 1,226 ounces; but the impulſe and weight are 6 ounces, and 1,226 taken from 6, the remainder is 4,774 ounces the impulſe of the water, which is above $\frac{3}{4}$ more than the weight: and if we take 2 inches in length the impulſe will then be conſiderably more than the weight. I am of the opinion, that in the 3d experiment, the impulſe is $\frac{3}{4}$ more than the weight of the water; but then the power muſt be to the reſiſtance as 2 to 1, or upwards; elſe this great impulſe will not take place, for water acts upon wheels very differently under different circumſtances, as I ſhall ſhew at large in the third part. This great impulſe of water will ſcarcely meet with credit; but in the third part I ſhall deſcribe the ſaw mills in America, which are moved ſolely by

the impulfe of the water; and their great effect will corroborate with the above, and abate the wonder which this may excite.

The following table is calculated by the foregoing rules, deduced from experiments, for the benefit of thofe who may not be able to calculate.

TABLE III.

Depth in feet.	Dimenfions of the areas.	The impulfe & wt. of water acting upon the wheels in lbs.	Depth in feet.	Dimenfions of the areas.	The impulfe & wt. of water acting upon the wheels in lbs.
1	24 by 6	47.	1	48 by 6	95.
2		95.	2		190.
3		143.	3		285.
4		198.	4		380.
1	24 by 9	68.	1	48 by 9	140.
2		136.	2		286.
3		204.	3		429.
4		272.	4		572.

Note, by doubling the depth, or areas, the number of pounds will be double: or by dividing any of the depths or areas, the number of pounds will be in proportion to the depths or areas fo divided. By which it may appear, that it makes no difference whether the depth or area be doubled; but there is a material difference, for a double area will require twice the quantity of water that doubling the depth will require.

It appears by experimennts, that the flowing of water through apertures of different depths, is in direct proportion to the depths and ſquare inches of the apertures: but the velocity or length of the flowing ſtream, is invariably 6,28 feet per ſecond in all the experiments; and it is the increaſe of the column of water, that momentarily flows through the apertures, which cauſes the increaſe of the quantity according to increaſing depth, or preſſure of water above the orifice.

Although I affirm, that water flows out at an aperture 6,28 feet per ſecond, it is not to be underſtood that I mean the column of water flows the length of 6,28 feet in a ſecond; but that the velocity at the area (viz. 1 inch in length) flows at the rate of 6,28 per ſecond. For as ſoon as it quits the opening it is retarded, both by the reſiſtance of the air, and its natural tendency to deſcend by its weight, according to the laws of projectiles. There is no doubt but water, like all other ponderous bodies, will deſcend by its weight, when in free ſpace; but this is not the caſe of water acting upon wheels.

It is proved by the 3d experiment, that the velocity of water at the aperture is equal to the velocity of the wheel, which is 6,28 feet per ſecond, but the impulſe and weight of the water at the horizontal arm of the wheel continues to act upon

it but a very ſmall ſpace of time; I compute it not more than 4-60 of a ſecond, as I ſhall make appear by the following ſtatement, in experiment the 3d.—4794 ſquare inches of water, run out at an aperture 3,45 ſquare inches in 30 ſeconds, the water ſtanding upon a level at 4 inches deep before it was let upon the wheel.—4794 divided by 30, the quotient is 159,8, this number of inches carried the wheel once round in a ſecond, and by dividing 159,8 by 75,36 the number of inches in the circumference of the wheel, the quotient is 2,120475, the area of the ſtream of water 1 inch in length, at the aperture; and by multiplying this area by 5 the product is 10,602275, this divided by 1,728, the weight of 1 ounce of water, the quotient is 6,1 ounces, a little above twice the reſiſtance.

The weight at the axle 36 ounces, and the power at the wheel 6 ounces, the radius of the wheel 12 inches, and the radius of the axle 1 inch, the proportion is as 1 : 12 :: 6 : 72; hence the power is to the weight as 2 to 1. From which it appears, that the area of the flowing water acts upon the wheel not more than 5 inches in length, excluſive of the impulſe, which muſt contribute towards turning the wheel: but as it is difficult to determine how much the impulſe may amount to, we may with certainty conclude, the weight and impulſe conjointly did not act upon the wheel more than 5 inches in length of the area, and not more than

4-60 of a ſecond of time. The reſt of the experiments may be proved by the ſame proceſs.

I have given this explanation to ſhew by what means I account for water flowing out at apertures 6,28 feet per ſecond; and any one may, by the ſame experiments, find that what I advance is fact, if he purſues the ſame proceſs that I was neceſſitated to make uſe of, viz. what may be called a perpetual fountain, by turning a 17-gallon caſk full of water into a tub of the ſame, to ſupply the want of a ſtream or body of water.

Note, I tried experiments with ſmall tubs, in the bottoms of which were holes, and found that the quantity of water was ſhort of the foregoing experiments, which I attributed to the collateral and various directions in which it endeavoured to arrive at the opening, as it thereby cauſed a confuſed and agitated obſtruction in its paſſage. But in the foregoing experiments the water was confined in the channel to the width of the area, ſo as to run in a parallel direction to the opening, and to flow directly through it; thereby, in ſome meaſure, producing the effect of water paſſing through a ſhort tube, viz. an acceleration of its motion; and, I preſume, occaſioning the difference in quantity of the tub and cloſe channel.

PART III.

Of constructing Wheel Machines, &c. to the greatest Advantage; also the applying Water to Wheels; with Rules to find the Power, Velocity, and Effect of Water upon Wheels, deduced from actual Experiments.

THE following rules are deduced from the 3d and 4th experiments, in the second part; where it is proved, that when the moving force of the water is equal to the resisting force, the wheel moves with the velocity of 3,14 feet per second; and when the force of water is twice the resisting force, the wheel moves with the velocity of 6,28 feet per second. I find, by the 4th experiment, that when the natural flowing of the water, at 4 inches depth, by the 3d experiment, viz. 2,12 inches, is a balance to the 72 ounces in the 4th experiment; and if the weights were dead weights, neither would preponderate: but water meeting

with a reſiſtance that exceeds its natural weight and impulſe, collects till it overcomes the reſiſtance; as was the caſe in the 4th experiment, in which it roſe to double its former height, and gave the reſiſtance of the 72 ounces 3,14 feet velocity per ſecond: we therefore find that 3,14 is a general mean between the power of water and the reſiſtance, viz. by dividing the power by the reſiſtance, then as the reſiſtance is to 3,14, ſo is the power to the velocity: thus the power being 2, and the reſiſtance 1, then as 1 : 2 :: 3,14 : 6,28 the velocity; alſo, as 2 : 6,28 :: 1 : 3,14; and as 1 : 3,14 :: 1 : 3,14; conſequently by making 1 the firſt term, 3,14 the ſecond, and the power the third, the fourth proportional will be the velocity of the wheel, let the power and reſiſtance be what they may. The following examples will make it plain; and will not only find the velocity of the wheel, but alſo the power and reſiſtance. When any two of them are given, 3,14 is always one of the terms.

Case 1.—The moving and reſiſting force given to find the velocity.—*Rule;* multiply the power by 3,14, and divide by the reſiſting force; the quotient is the velocity.

Example 1ſt: the power given 200, and reſiſtance 100, what is the velocity? As 100 : 3,14 :: 200 : 628 the velocity.—*Example* 2d: the power

given 100, and the reſiſtance 80, what is the velocity? As 80 : 100 : : 3,14 : 3,92 the velocity.—*Example* 3d: the power given 300, and the reſiſtance 200, what is the velocity? As 200 : 300 : : 3,14 : 4,71 the velocity required.—By this rule may be found the power and reſiſtance promiſcuouſly given.

CASE 2.—The power and velocity given to find the reſiſtance.—*Rule;* multiply the power by 3,14, and divide by the velocity; the quotient is the reſiſting force.

Example 1ſt: the power given 100, and the velocity 5, what is the reſiſtance? As 5 : 3,14 : : 100 : 62,8 the reſiſtance.—*Example* 2d: the power given 150, and the velocity 7, what is the reſiſtance? As 7 : 3,14 : : 150 : 67,85 the reſiſtance.—*Example* 3d: the power given 200, and the velocity 9, what is the reſiſtance? As 9 : 3,14 : : 200 : 69,777 the reſiſtance.—*Example* 4th: the power given 90, and the velocity 4, what is the reſiſtance? As 4 : 3,14 : : 90 : 70,65 the reſiſtance. —*Example* 5th: the power given 400, and the velocity 6,28, what is the reſiſtance? As 6,28 : 3,14 : : 400 : 200.

CASE 3.—The velocity and weight, or reſiſtance, given to find the power.—*Rule;* as 3,14 is to the velocity, ſo is the reſiſtance to the power.

Example 1ſt: the reſiſtance given 150, and the velocity 4,71, what is the power? As 3,14 : 4,71 :: 150 : 225 the power.—*Example* 2d: the weight given 50, and the velocity 5, what is the power? As 3,14 : 5 :: 50 : 79,966 the power.—*Example* 3d: the weight given 100, and the velocity 1,57, what is the power? As 3,14 : 1,57 :: 100 : 50 the power. *Example* 4th: the weight given 40, and the velocity 6, what is the power? As 3,14 : 6 :: 40 : 76,43 the power.

We may obſerve that 3,14 is the general mean proportional between the reſiſting force and moving force; and by dividing any power by the reſiſtance, the difference is the firſt term, 3,14 the ſecond, and the power the third; the fourth proportional is the velocity.

Example; ſuppoſe the power 200, and the reſiſtance 100; here the proportion is as 2 to 1; then as 1 : 3,14 :: 2 : 6,28 the velocity. Let the power be 150, and the reſiſtance 100; here the proportion is as 1 to 1,5; and as 1 : 3,14 :: 1,5 : 4,71 the velocity.

From which we deduce a general rule to find the velocity of any propoſed power of water acting upon wheels; for as 1 is the firſt term of the proportion, by multiplying the given or propoſed

power by 3,14, the product will be the velocity: by which the following table is calculated, increasing by one-fourths.

TABLE IV.

As the resistance 1 is to	Power	so is 3,14 to	Velocity	As the resistance 1 is to	Power	so is 3,14 to	Velocity
	,25		,585		2,25		7,056
	,5		1,570		2,50		7,850
	,75		2,355		5,75		8,635
	1,00		3,140		3,00		9,420
	1,25		3,925		3,25		10,205
	1,50		4,710		3,50		10,990
	1,75		5,492		3,75		11,775
	2,00		6,280		4,00		12,560

By making the maximum the first term in the proportion, its velocity the second, and the resisting force the third, the result will be the same. Thus, as 2 the power is to 6,28 its velocity, so is any other power to its velocity. As 2 : 6,28 :: ,25 : ,785 the velocity; as 2 : 6,28 :: 1 : 3,14; as 2 : 6,28 :: 1,5 : 4,71 the velocity. But by making 1 the general resistance, we need only multiply the powers by 3,14, and the product is the velocity; which is a much shorter process.

Thus we can calculate velocity to any extent we please; but we can carry it to no great length in practice, because the laws of nature prevent it. The friction on the centre, and the resistance of the air at the circumference, both increase with

the velocity; ſo that velocity is the cauſe of its own limitation, and not the laws of falling bodies, as is generally ſuppoſed. A power of 6 to 1 of reſiſtance, the velocity would be 18,84 feet per ſecond: and a power of 8 to 1 reſiſtance, the velocity would be 25,12, if not prevented by the above-mentioned impediments. But our reaſon tells us, ſuch violent velocities are impracticable; and if they were practicable, the friction at the centre would ſet the machine on fire.

From the foregoing table of the action of water upon wheels, we may draw deductions of the utmoſt importance. The firſt and moſt material obſervation is, that when the power is to the reſiſtance as 2 to 1, and the velocity 6,28, the water acts upon the wheels to the greateſt advantage poſſible; and may be called the maximum of water thus acting, as in fact it is: but this will not be the caſe except under particular circumſtances.

Mechanics, I ſuppoſe, will conclude, that when water is let upon the wheel of double the weight of reſiſtance, the wheel will acquire this velocity of 6,28 feet per ſecond. This ſuppoſition ſeems to miſlead all mechanics, as it has heretofore myſelf; but water will not produce this velocity except under certain circumſtances. The 4th experiment proves, that double the weight of water

in that cafe, only gives the wheel the velocity of 3,14 feet per fecond; but by doubling the depth of water, the fame weight of water gave the wheel 6,28 feet per fecond: hence it is not the weight, but the impulfe of the water, which principally governs the velocity of the wheel.

But the great advantage of the impulfe of water will not take place, unlefs the depth and column of water be particularly adapted to bring about the maximum; for it is limitted to certain circumftances. When the power of water is to the refifting force as 2 to 1, and the velocity is 6,28 feet per fecond, we have a particular right to call it the maximum, from its fuperior advantages to all the other proportions and velocities in the table, under or lefs than the maximum; all of which will require more water per fecond to procure their velocities than the maximum, although the fame refiftance is oppofed to each.

The beft informed mechanics generally conclude, that the maximum of water acting upon wheels, is when the wheel moves with one-third of the velocity of the flowing water, and the power is to the refiftance as 9 to 4; then they conclude the machine is in the greateft perfection.

That they are generally miftaken, I can prove by experiments, which I have repeatedly done.

By the impulſe and weight of water being as 2 to 1 of the reſiſtance, and the power being 9 to 4, the proportion is as 2,25 to 1; therefore as 2 : 6,28 :: 2,25 : 7,065 feet the velocity. This I can prove by experiment, by adjuſting the water ſo as to have the greateſt effect upon the wheel; I believe I can alſo order it ſo, that the ſame ſtream and area which cauſed the velocity of 7,065 feet per ſecond, ſhall only have the velocity of 2,093 feet per ſecond, although the weight of water ſhall be in this caſe about three times as much as when the velocity was 7,065 feet per ſecond. This will be looked upon as a paradox, and will ſcarcely be credited; but the great variety of the flowing of water through areas from different heighths, and effects upon wheels, will afford ſeveral cauſes as ſtrange as the above, which former authors ſeem to have had no idea of, and I have therefore a juſt right to the firſt diſcovery.

From the 3d experiment we may find the proportion of the impulſe to the weight of water acting upon wheels, when the effect is a maximum. The area or ſtream of flowing water was there 2,12049, and the impulſe and weight conjointly was 10,368 ſquare inches, equal to 6 ounces in weight, acting upon the wheel; and the weight of 2,12049 inches of water is 1,227 ounce, and 1,227 taken from 6 ounces, the remainder is 4,773 ounces the impulſe; by which it appears the im-

pulſe is to the weight of water acting upon the wheel nearly as 4 to 1.

By inſpecting Table IV. we may obſerve, that by receding from the maximum of 6,28 velocity, we gradually loſe velocity; and when we come to 3,14 the water accumulates in the channel to twice the depth it was at when the velocity was 6,28; and although the water ſupplied the wheel with double the weight of the reſiſtance, it only gave the wheel the velocity of 3,14 feet per ſecond: here it is evident that half the impulſe is loſt, and double the weight of water inſtead thereof:—and at ,785 velocity we loſe nearly the whole of the impulſe, and in its place four times the quantity of water; and as water has but about one-fourth the power of impulſe, the loſs of velocity is obvious.

Here we diſcover a notable difference between a power of water and other powers: with the wheel and axle we gain weight to compenſate the loſs of velocity; but in the table we diſcover, by receding from the maximum we exchange impulſe for water, which has not more than one-fourth of the power of impulſe, when applied to the greateſt advantage.

Note, when the velocity of wheels is 6,28 feet per ſecond, it appears, by all the experiments I

have made, that the flowing water and the wheel have exactly the same velocity; and I believe I could, with a convenient situation of water, so order it that the same stream of water and area should produce all the velocities contained in Table IV. under 6,28. In short, I find such a variety in the effects of water upon wheels, as is sufficient to excite wonder, and is scarcely creditable; but as the work is put to press I must haste to finish what I have further to add.

The Utility of Tables III. *and* IV.

The ingenious mechanic, before he sets about constructing a machine, ought to fix or determine, as near as he can, the velocity necessary, according to the use it is intended for: and he ought also to consider what resistance the machine will give, that he may proportion the power accordingly. Suppose he would have his machine to move with the velocity of 6,28 feet per second, look in the table (No. III.) for the number of pounds he may judge proper for his power, suppose 285; in the last column of the table, and in the next column, to the left, is 48 inches by 9 for the area; and in the column under depth in feet, he will find the number 3 for the depth; then take half 286=143 for the resisting force, which is as 1 to 2:—this

depth and area will give the machine the velocity of 6,28 feet per ſecond, abating for friction, which in general is not near ſo much as is imagined; mechanics find many ways to cauſe reſiſtance, exclusive of friction, &c.

Suppoſe the mechanic would have his machine move with 4,71 feet per ſecond, then the power to the reſiſtance muſt be as 1,5 to 1; let the ſame power 286 be the number of pounds, then the depth and area will be the ſame; and as 1 : 1,5 :: 286 : 190 the reſiſting force: the moving force to the reſiſting force is as 286 to 190; the depth 2 feet and area 48 inches by 9 will give the machine the velocity of 4,71 feet per ſecond.

Suppoſe the velocity 3,14 feet per ſecond, the depth, power, and area the ſame. In Table IV. over againſt 3,14 is as 1 is to 1, which ſhews the moving and reſiſting force to be equal, or a balance to each other; therefore 286 power, and the ſame reſiſtance, will have the velocity of 3,14 feet per ſecond, and all theſe three different velocities have the ſame depth and area. Therefore by fixing upon any velocity in Table IV. the proportion of the power to 1, the general reſiſtance in the table, is ſhewn at the left hand, over againſt the velocity; and I have ſhewn above how to proceed with any

velocity, and the proportion, power, and reſiſtance, correſponding thereto.

Note, the foregoing rules and obſervations will not apply to any machines but thoſe conſtructed with balance wheels, &c.

To apply Water to Wheels to the greateſt Advantage.

Fix the centre of the wheel 16 or 18 inches below the bottom of the channel which conveys the water to the wheel, the channel to be the width of the inſide rim of the wheel, and depth in proportion to the quantity of water it has to convey.

Let the bottom of the channel have an opening next the wheel, as wide as the wheel, and 6, 8, or 10 inches broad, more or leſs, as the caſe may require; let a board be fixed from top to bottom of the channel, next the wheel, and cloſe to it; this board will be on one ſide, next the wheel, of the ſquare opening for the water to flow through, and muſt incline a little to direct the water to ſtrike the float-boards in the middle, as near as may be at the horizontal arm of the wheel; let the floats be 15 or 16 inches apart, and pointing to the

centre of the wheel, which will be of more advantage than if they inclined to the wheel, becauſe then the water would ſtrike them more oblique.

The mechanic is to obſerve, the whole intention of this contrivance is to direct the water to ſtrike the floats as near as may be at right angles, at the horizontal arm of the wheel, by which the water will have the greateſt advantage poſſible.

Of the Size of Wheels, &c.

I presume why large wheels ſtill prevail, is by ſuppoſing that the greater weight of water upon the wheel the greater power; this is proved by the foregoing experiments not to be the caſe, and that a breaſt wheel, and the water applied to the greateſt advantage, will have nearly double the power of any over-ſhot wheel, with equal advantage of water. Another reaſon why large wheels prevail is by ſuppoſing, that by lengthening the lever we gain power: this is alſo vague and imaginary; and is what miſleads both mechanics and mankind in general. Levers can never be introduced into a train of wheels but to diſadvantage; their whole action, as a mechanic power, proceeds from their being artificial balances, and whatever weight is

gained thereby, an exact equivalent in velocity is loſt; and velocity is the moſt eſſential thing to be regarded in wheel machines: hence levers ought to be excluded from wheel machines as much as poſſible.

As the weight of water in the buckets may be proved of no uſe, when the velocity is 3,14 and upwards; nor the ſuppoſed advantage of the gravitating force of the water paſſing through the half-circumference of the wheel, nor the lengthening of the radiuſes of the wheels, is of any advantage; it is evident that large wheels only add weight and friction, without giving any additional power: therefore it is clear we gain advantage by contracting the wheels of machines, as much as the caſe will admit; as the effect of wheels depend not upon their ſize, but their proportion, &c. This contraction depends much on the power to be applied: if a man's ſtrength, it admits of the greateſt contraction, for he may exert his ſtrength to the utmoſt advantage, by turning a 12-inch handle: if the power is a horſe, we cannot apply his ſtrength but to the greateſt diſadvantage, becauſe he requires ſo great a circle to walk round: if a power of water, the wheels may be 2, 3, 4, or 5 feet radius, according to the reſiſtance. But I believe a four-feet radius wheel is large enough for any purpoſe whatever; a two-feet radius wheel may do in

many cafes, when the refiftance is not great; and a three-feet radius wheel is fufficient for a mill to grind corn with one pair of ftones. In all cafes we fhould be careful to proportion the rim of the wheel to the required quantity of water.

By fmall wheels we gain many advantages, as they require lefs timber, lefs labour, are ftronger, and, above all, the convenience of erecting a mill in almoft any fituation, as they require but a fmall fall; whereas large over-fhot wheels can only be erected where there is a great fall, and are often attended with a heavy expence, and confiderable labour.

As to the proportioning of wheels I have nothing to add, as I have all along endeavoured to inculcate, that a water and cog wheel of equal radiufes and a one-foot trundle, is the greateft advantage that the laws of the mechanic powers will admit of; as the power is conveyed from the water wheel to the refiftance at the trundle, without abatement, except the friction; and if the refiftance acts at the fame diftance from the centre with the trundle, viz. 1 foot radius, the power and refiftance will be equal, or a balance to each other. But this may feldom or never be exactly the cafe; and if the refiftance be more than 1 foot from the centre, it will act as a lever againft the

power. For example; in a mill to grind corn, the corn gives no reſiſtance at the centre, but increaſes all the way to the circumference; hence we cannot take the mean reſiſtance at leſs than two-thirds the radius of the ſtone; this conſtitutes a lever againſt the trundle; and if the mill ſtone is 5 feet diameter, the reſiſtance againſt the trundle will be as 20 to 12; yet we cannot make the trundle larger or ſmaller, to gain any advantage: ſuppoſe we make it 20 inches radius, the power and reſiſtance will be a balance; but to carry the mill ſtone once round in a ſecond, the velocity of the wheels muſt be 10,416 feet in a ſecond; for as 12 : 20 : : 6,28 : 10,416: on the other hand, if we leſſen the trundle to 6 inches, it will increaſe the reſiſtance double; and, although 3,14 feet per ſecond will move the mill ſtone once round in a ſecond, yet it requires twice the quantity of water, as is proved by the 4th experiment. Hence a one-foot radius wheel or trundle, is the maximum of wheel machines. In Table IV. all the proportions of the powers and reſiſtances act at equal diſtances from the centre, conſequently a balance to each other; but in this caſe of the mill ſtone giving a reſiſtance as 20 to 12, the lever cauſes a great diſadvantage; ſuppoſe the power 200lb. and the reſiſtance 100 lb. if the power and the reſiſtance acted at equal diſtances from the centre, the 200 lb. power would give the velocity of 6,28 fee

per ſecond, with the 100lb. reſiſtance. But as 20:12::6,28:3,768 the velocity that 200 lb. will give when the reſiſtance is as 20 to 12; yet the velocity required is 6,28, therefore as 3,768:6,28 ::200:331 lb. the power required to give 6,28 feet per ſecond, when the reſiſtance is as 20 to 12; and ſo for any other power and reſiſtance.

The deſcription of a ſaw-mill wheel in America, which is moved wholly by the impulſe of the water, will abate the wonder that the great impulſe I have given to water, may excite in the learned mechanic.—This ſaw-mill was near to where I lived ſeveral years, and which I have often contemplated with admiration, conſidering its ſimpleneſs and great effect. The wheel was about 2 feet radius, and its width 4 feet; the water flowed upon it from the heighth of 5 or 6 feet above the wheel, from a large reſervoir; the float-boards were about 9 or 10 inches wide, all pointing to the centre; the middle of the wheel quite open, and had no buckets; the crank which worked the ſaw, was the ſame radius as the wheel, conſequently a balance; the frame of the ſaw moved up and down in a frame, without any rollers to eaſe the rubbing; the logs to be ſawed were confined to a frame which dragged along the floor, ſome of which were 16 or 20 feet long, and 12 or 14 inches ſquare: with all this reſiſtance, this little four-feet

diameter wheel moved with the velocity of 7 or 8 feet per ſecond, which was cauſed by the momentary impulſe of the water; for as ſoon as it had ſtruck the wheel it flew off in a thouſand directions. The action of water upon this ſaw-mill wheel is a clear demonſtration, that the advantage ſuppoſed to be obtained by the weight of water in the buckets of wheels, is quite a deluſion, as I have ſufficiently made manifeſt in my experiments.

I ſhall now give a deſcription of a corn mill, ſaid to be the beſt in the kingdom: we may with truth ſay it is the beſt ſituation in the kingdom; as any thing which can be obtained by the power of water, may be accompliſhed in this place. This mill is at the ſeat of Lord Ducie Mortons, in Glouceſterſhire: it is ſupplied with water from a large fiſh pond, which covers ſeveral acres of ground; the deſcent or fall cannot be leſs than 50 feet perpendicular; the water wheel is 32 feet diameter, and the cog wheel 16, which turns a ſmall wheel about 4 feet diameter, on a vertical axle, upon which is a ſpur wheel 12 feet diameter, which turns the three trundles. The water wheel is an over-ſhot one, and the water flows upon it 16 feet below the ſurface of the pond: the trundles we will ſuppoſe 2 feet diameter, as that ſize is the moſt advantageous.

Firſt, we may obſerve, the water wheel being twice the radius of the cog wheel, we loſe half the velocity. With balance wheels, ſuppoſe the power 400 lb. and the reſiſtance of the corn 200lb. the proportion will be as 200 : 3,14 :: 400 : 6,28 the maximum; but here the velocity of the cog wheel will be 3,14 when the water wheel moves with the velocity of 6,28 feet per ſecond; therefore the wheel muſt move 12,56 feet, to give the velocity of 6,28 to the cog wheel: this cannot be accompliſhed by any other means than by doubling the power; this I am confident is fact, ſee Table IV. 3,14 velocity, and the explanation. This is one of the greateſt myſteries in mechanics, and ought to be determined by experiments; if it is found to be fact (which I have no doubt of,) it leads mechanics in general into error. I ſuppoſe this loſs of velocity in this mill, is intended to be regained by the proportion of the ſmall wheel on the upright axle which the cog wheel turns, to the ſpur wheel which turns the trundles (here the remedy is worſe than the diſeaſe), the ſmall wheel being in proportion to the ſpur wheel as 1 to 3, it requires three times the power, and upwards, to move the reſiſtance at the trundles. Hence this train of wheels requires three or four times the power of the balance wheels to equal their effect. Had the cog and water wheel been of the ſame diameters, and the trundles 2 feet diameter, and a wheel of any convenient diameter upon an up-

right axle, with a double ſet of cogs, one ſet for the cog wheel to turn it, the other to turn the trundles; or if this was not convenient, two wheels might have been upon the upright axle. With ſuch a train of wheels, the power at the water wheel would have been conveyed to the trundles without any abatement (except friction), and would have met the reſiſtance of the corn at the trundles with its full force.

I make no doubt but I could direct the conſtruction of three corn mills in that ſituation, one above another, all to be moved by the ſame ſtream, and each of them to have nearly, if not quite, as great an effect as the preſent enormous load of wheels.

I here preſent the public a new doctrine of mechanics, more eſpecially the extenſive and various effects of water, which differs much from the general opinion of all the learned mechanics who have treated on the ſubject. So different, that it ſcarcely will be credited; but I beg the public not to cenſure it too haſtily, without proper examination:—facts which may be proved by experiment, are not to be overturned by conjecture.

I have diſcovered the true means to eſtabliſh a ſyſtem of the various effects of water; but to extend it to the utmoſt of its uſefulneſs, more ex-

periments are neceſſary, which it is out of my power, in my preſent ſituation, to execute, for want of a body or ſtream of water proper for the purpoſe. It would complete the utmoſt of my wiſhes, for the ſmall remainder of my life (which I cannot expect to be long) to reſide in a ſituation where a proper ſtream of water might be had for experiments, which I think neceſſary to complete a true ſyſtem of water; which I look upon as a moſt extenſive and uſeful power, far exceeding dead weights, the ſtrength of men or animals. But I have no proſpect of its being in my power to chooſe ſuch a ſituation, although it might benefit the public more than myſelf, by the uſeful diſcoveries I might make.

In my preſent ſituation, what improvements I may make I will communicate them to the world, if my life is prolonged to publiſh a ſecond edition; therefore, I ſhall conclude with the ſame opinion I ſet out with,—*that the laws of mechanics are the leaſt underſtood of any uſeful branch of ſcience whatever.*

FINIS.